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An Investigation of the Perception of Tone Quality
Changes During Conventional Tone Decay Test Procedures
with Normally Hearing Human Subjects

By

Anne M. Cook
B.S., University of Washington, 1983

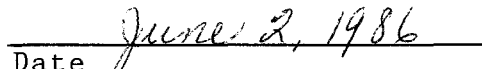
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for the degree of

Master of Arts
University of Montana
1986

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Chair, Board of Examiners


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Communication Sciences
and Disorders

An Investigation of the Perception of Tone Quality Changes During
Conventional Tone Decay Test Procedures with Normally Hearing Human
Subjects (55 pages).

Director: Michael K. Wynne, Ph.C. *MKW*

The purpose of the present study was to determine if normally hearing subjects perceived a change in tone quality during a standard tone decay test procedure. It was predicted that normally hearing subjects would not perceive a change in the tonality of the stimulus unless they were instructed to do so. The procedures involved the administration of the Olsen-Noffsinger test of tone decay to the right ears of 40 subjects drawn from the University of Montana. The subjects were divided into four groups: Group A, who received a continuous stimulus combined with pretest instructions; group B, who received a continuous stimulus combined with posttest instructions; group C, who received a pulsed stimulus combined with pretest instructions; and finally group D, who received a pulsed stimulus combined with posttest instructions. The subjects in all groups were required to have normal hearing and normal tympanograms.

The results of the study using X^2 analysis indicated that neither instructional set or type of stimulus had a significant effect upon the subject's responses. Although these results were not statistically significant, the size effects indicated that instructional set may have an effect on standard tone decay test results.

Further research is suggested since these findings indicate that current tone decay test results may be influenced by more than the nature of the protocol or the nature and integrity of the auditory system.

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TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGMENTS.....	iii
TABLE OF CONTENTS.....	iv
LIST OF FIGURES.....	v
LIST OF TABLES.....	vi

Chapter

I.....	1
II.....	29
III.....	32
IV.....	44
BIBLIOGRAPHY.....	50
APPENDIX A.....	53
APPENDIX B.....	54
APPENDIX C.....	55

LIST OF FIGURES

Figure	Page
1 The Four Types of Bekesy Sweep Frequency Tracings as Described by Jerger (1960).....	15
2 Observed Occurrences in Each Response Condition as a Function of Instructional Set.....	38
3 Total Observed Occurrences in Each Response Condition as a Function of Stimulus.....	39
4 Observed Occurrences in Each Response Condition as a Function of Stimulus.....	40
5 Total Observed Occurrences in Each Response Condition as a Function of Stimulus.....	41

LIST OF TABLES

Table		Page
1	Results of X Computations of Partitioned Tables for Perceived Changes as a Function of Instructional Set.....	42
2	Results of X Computations of Partitioned Tables for Perceived Changes as a Function of Stimulus.....	43

CHAPTER 1

INTRODUCTION

Tone decay testing is frequently used in audiometry to determine the existence of excessive auditory adaptation suggesting a possible retrocochlear lesion. The test consists of a constant intensity pure tone presented monaurally under earphones for at least a one minute duration, depending on the method used. The patient is requested to provide a response for as long as they can hear the tone. If the tone fades from the patient's perception, and continues to fade as the intensity is gradually raised 30 dB SL or more, the test is considered to be positive for tone decay, suggesting the possibility of a retrocochlear lesion (Sorensen, 1961).

Some investigators have noted that patients with retrocochlear disorders often report a change in the quality of the tone during its presentation or shortly before it fades from perception, i.e. the tone is perceived as a buzz or will change pitch (Green, 1963). This change in the timbre or quality of the tone also

has been considered to be indicative of retrocochlear disorder (Green, 1963). However, Green did not obtain experimental data related to the hypothesis, and very little data has been accumulated in regards to this phenomenon. Two studies have investigated tone quality change (Parker, 1968; Barratt and Hood, 1984). Barratt and Hood (1984) suggested that normal listeners as well as those with retrocochlear lesions perceive change in tone quality. They reported that their normal hearing subjects experienced a change in the perceived quality of a pure tone when it was presented to the subjects for one minute or longer. Tones were presented to the subjects under two conditions. One condition had the subject make a comparison between the stimulus tone and a one-second tone in the other ear to detect if a difference existed. The second condition used no comparison tone. The subjects indicated perceived changes in quality at 30 second intervals during the total five minute presentation time. The tones were presented at three listening levels: 80, 50 and 40 dB HL. Every subject indicated a change in the perception of the tone quality during the five minute presentation time. The initial change was abrupt and further change leveled off as the duration of the presentation increased. Statistical analysis indicated that

intensity was not significantly related to the tone quality change.

Clinically, however, it is more practical to use shorter tests to determine if a patient is experiencing abnormal adaptation or a change in tone quality. Most measures of tone decay use a duration of one minute for each presentation. If a change in tone quality is perceived by normal listeners using a standard test protocol, then assessment of tonal quality may not be a sensitive indicator of retrocochlear involvement.

ADAPTATION

Tone decay, or auditory adaptation, is defined as the temporary reduction in hearing sensitivity that results from sustained acoustic stimulation (Konkle and Orchik, 1979). The phenomenon of auditory adaptation is quite different from the phenomenon of auditory fatigue. Auditory fatigue is defined as a threshold shift that occurs after a stimulus ceases (Ward, 1973). For example, attendance at a loud concert might produce temporary auditory fatigue. Pure tone air conduction thresholds may be obtained at hearing levels 5 to 10 dB

poorer than those thresholds obtained before the subject is exposed to the noise. Typically reduced thresholds from auditory fatigue return to normal within 24 hours (Martin, 1981). Auditory adaptation is a reduction or "decay" in the perceived loudness of a stimulus tone during the presentation of the tone (Ward, 1973).

Adaptation is different from fatigue in that recovery is more rapid once the stimulus ceases. This phenomenon is due to the nervous system's capability of adapting to all forms of continuous stimulation, including auditory stimulation.

Although the physiologic basis for tone decay is not completely understood, numerous investigators have defined three classifications of neural activity which may account for the perception of a signal at or above threshold.

- 1) The "on-effect", which is a burst of neural activity at the onset of stimulation or presentation of a tone,

- 2) Neural adaptation or equilibration, which is a general reduction of neural activity once the stimulus has been presented, and

- 3) The "off-effect", which is a final burst of neural activity when the stimulus ceases (Aran, 1973).

The above pattern is seen in the normally hearing

ear. During the adaptation phase, the nerve cell activity gradually decreases. One explanation for abnormal adaptation might be that a lesion in the system would reduce the number of nerve fibers responding to the stimulus. Another explanation could be that the nerves are unable to sustain continuous firing during constant stimulation, so an abnormal degree of adaptation will be measureable (Ward, 1973). Abnormal adaptation is defined when a patient requires the stimulus to have a sensation level of 30 dB or higher before the patient is able to perceive the tone for a full 60 seconds (Yantis, 1959). Thus the pathological ear adapts so quickly that the stimulus appears to fade from perception. This abnormal adaptation suggests a dysfunction in the auditory nervous system and is generally considered to be indicative of a retrocochlear lesion (Hood, 1956; Carhart, 1957; Rosenburg, 1958; Green, 1963; Owens, 1964; Parker, 1968; Olsen and Noffsinger, 1974; Jerger and Jerger, 1975).

STIMULUS EFFECTS

Frequency

The nature of auditory adaptation is dependent on several parameters of the stimulus. One critical parameter is the frequency of the stimulus. In the normal ear, a pure tone stimulus can generally be heard for a full 60 seconds (at threshold) in the frequencies below 2000 Hz. In the higher frequencies, a sensation level of 5 dB is often necessary to obtain a response (Carhart, 1956). Several investigators have reported tone decay results that varied tremendously in the frequencies above 4000 Hz (Yantis, 1959; Owens, 1964; Green, 1968). Owens (1964) compared tone decay results for a group of patients diagnosed as having Meniere's disease with a group diagnosed as having retrocochlear lesions. He reported that abnormal tone decay was more indicative of retrocochlear lesions if it was observed in the frequencies below 2000 Hz. If tone decay was restricted to one or two of the higher frequencies the hearing loss tended to be cochlear in nature. Karja (1976) reported that as the frequency of the stimulus increased, adaptation also increased on a roughly linear basis until 2000 Hz, where it then stabilized.

The appearance of abnormal tone decay in the low frequencies being suggestive of retrocochlear involvement can be explained by the tonotopic arrangement of the fibers in the VIII cranial nerve. Tuning curve research indicates that the VIII cranial nerve is tonotopically arranged such that the high frequency fibers lie on the outside and surround the lower frequency fibers on the inside. Theoretically the outside fibers will be the most vulnerable to lesions in the internal auditory meatus and at the cerebello-pontine angle (Nager, 1985). Any lesion will first affect the high frequency fibers on the outside of the nerve and then the continued growth of the lesion will exert pressure throughout the nerve and may affect a few or many low frequency fibers depending on the size of the lesion (Stroud and Thalman, 1969). Owens (1964) reported that during tone decay testing, the frequencies involved usually had a progression from high to low. That is, of his test frequencies from 250 to 4000 Hz, if only one frequency was involved it was 4000 Hz; similarly if two frequencies showed decay these frequencies were typically 2000 and 4000 Hz, and so on. If tone decay occurred at low frequencies it almost always occurred in the higher frequencies as well. The patients with only high frequency tone decay tended to

have cochlear hearing losses, while those with decay across frequencies tended to have retrocochlear involvement. To summarize, tone decay is more likely to occur in the high frequencies as a result of both cochlear and retrocochlear dysfunction. In retrocochlear lesions this is most likely due to the tonotopic nature of the VIII nerve fibers and the manner in which they are affected by retrocochlear lesions (Brackman, 1984). However, there are greater numbers of cochlear lesions associated with high frequency tone decay. Therefore, tone decay that is present in the low frequencies is felt to be more indicative of a retrocochlear lesion than tone decay that is restricted to the higher frequencies.

Intensity

The intensity of the stimulus is also a critical factor in the assessment of pathological adaptation. As intensity is increased, the consistent appearance of tone decay is increasingly specific for a retrocochlear disorder (Carhart, 1956; Yantis, 1959; Olsen and Noffsinger, 1974; Jerger and Jerger, 1975; Wiley and Lilly, 1980). In contrast, in the normal ear and ear with a cochlear lesion, adaptation decreases as

intensity increases. Any abnormal tone decay which may occur in ears with cochlear lesions is probably due to retrocochlear VIII nerve fiber degeneration that accompanies the cochlear disorder (Owens, 1964). Therefore as the intensity of the stimulus is increased, more fibers are stimulated due to the increasing spread of the travelling wave envelope which enables the patient to perceive the tone without an abnormal degree of adaptation. However, in ears with retrocochlear lesions, it is hypothesized that the number of fibers that can fire is reduced, so fewer fibers are available as intensity is increased, and those firing will not be able to fire continually, thus resulting in abnormal tone decay (Sorensen, 1961).

Another explanation of tone decay in the presence of retrocochlear lesions is that retrocochlear disorders can cause a loss of signal transmission along the neuron itself. High firing rates of the individual nerve fibers cannot be maintained, which results in the loss of perception of the stimulus tone even when intensity is raised (Musiek and Gollegly, 1985).

TEMPORAL FEATURES OF ADAPTATION

The speed at which the patient experiences the tone

decay phenomenon can be used to assist in the evaluation of retrocochlear dysfunction. Wiley and Lilly (1980) reported that the evaluation of the magnitude of auditory adaptation as a function of time was effective in distinguishing retrocochlear from cochlear lesions. Owens (1964), and Karja (1976), reported that patients with retrocochlear lesions had much more rapid tone decay than those with cochlear lesions. As intensity increased, the patients with cochlear lesions had slower decay, while the patients with retrocochlear lesions had little or no change in the rapidity of tone decay, regardless of their threshold of hearing. Owens developed a classification system for these patterns of tone decay. Type I indicated those patients with no tone decay. Type II was used to delineate the patients with progressively slower decay. Owens assigned categories A through E to indicate the level above threshold at which adaptation was no longer perceived. For example, "II-A" referred to a patient who had tone decay at 5 dB above threshold, but met the one minute criterion at 10 dB SL. Type III was used to describe those patients who had little or no change in the rapidity of the decay regardless of the increase in intensity. According to Owens, Types I and II were characteristic of Meniere's disease, while Type III was

characteristic of retrocochlear lesions.

MASKING

Due to the asymmetry of some patient's hearing losses between ears or suprathreshold presentation levels, contralateral masking is sometimes indicated during tone decay testing. Masking is defined as the amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound (Katz, 1985). Contralateral masking is typically utilized in clinical testing to isolate the test ear. Masking can increase both normal and abnormal adaptation (Shimizu, 1969). Threshold increase is believed to be caused by the central masking effect. The central masking effect is a phenomenon seen when a stimulus is introduced to one ear, and a slight increase in threshold is seen in the other ear, even when the stimulus is not high enough in intensity to interfere acoustically with hearing threshold.

Shimizu (1969) reported that subjects with normal hearing and conductive losses who had negative tone decay test results when tested without masking, demonstrated 5 to 30 dB of increased tone decay when the opposite ear was masked at 40 dB SL. Of three

frequencies tested, the effect was most pronounced at 2000 Hz. Meyer et. al. (1975) reported that significant shifts in tone decay scores were seen when a contralateral masking noise was presented. They found that white noise and narrow band noise centered around the test frequency as opposed to conditions of no noise and narrow band noise centered above and below the test frequency induced the largest shifts in tone decay scores. Testing was performed at both 1000 and 2000 Hz, and the effect was also most pronounced at 2000 Hz.

CLINICAL MEASUREMENT OF ADAPTATION

There are four types of procedures used to measure adaptation: threshold and supra-threshold automatic Bekesy audiometry and threshold and supra-threshold pure tone techniques. The pure tone techniques are more time efficient than the Bekesy methods, but may be less sensitive.

AUTOMATIC AUDIOMETRY

Threshold automatic Bekesy audiometry involves an audiometer that automatically raises or lowers the presentation level of the stimulus tone based on the

patient's responses to the stimulus. If the patient responds to the test tone, the next stimulus is decreased in intensity. If there is no response, the intensity of the stimulus is raised. The pure tone signal is presented in a continuous and pulsed mode. For conventional sweep frequency Bekesy audiometry, the patient's threshold is tested using both pulsed and continuous tones in an ascending frequency pattern. By comparing the resulting tracings of continuous and pulsed tones, an assessment of site-of-lesion is possible.

Jerger stressed that comparison of the continuous and pulsed tracings is essential to accurate evaluation of adaptation. This can be accounted for by examining the "on effect" phenomenon of the neural fibers mentioned earlier. Once the stimulus fades from perception, an interruption in the signal will allow for recovery from adaptation. A patient with abnormal tone decay would gradually lose perception of the continuous signal, but would be able to hear the pulsed signal since it is continually re-presented. Adaptation is characterized by the continuous tone falling below the pulsed tone on the Bekesy patterns (Jerger, 1960).

Jerger (1960) described four patterns of tracings: A Jerger Type I pattern is characterized by an

interweaving of the pulsed and continuous tracings, with an excursion width of approximately 10 dB that is constant over frequency. Excursion widths as small as 3 dB and as large as 20 dB are not uncommon. A Jerger Type II pattern is characterized by the interweaving of pulsed and continuous tracings until approximately 1000 Hz, when the continuous tracing is poorer than the pulsed tracing by less than 20 dB. The excursion width of the continuous tracing is often as small as 3-5 dB in the higher frequencies. A Jerger Type III pattern is characterized by the early and dramatic separation of the continuous tone from the pulsed tone, often to the limits of the equipment. The excursion widths of the tracings remain normal, or similar to the width of a Type I tracing. A Jerger Type IV pattern is similar to Type II except that the continuous tracings will typically fall below the pulsed tracings at frequencies well below 1000 Hz. The excursion width may or may not become abnormally small. This tracing is frequently confused with Type II.

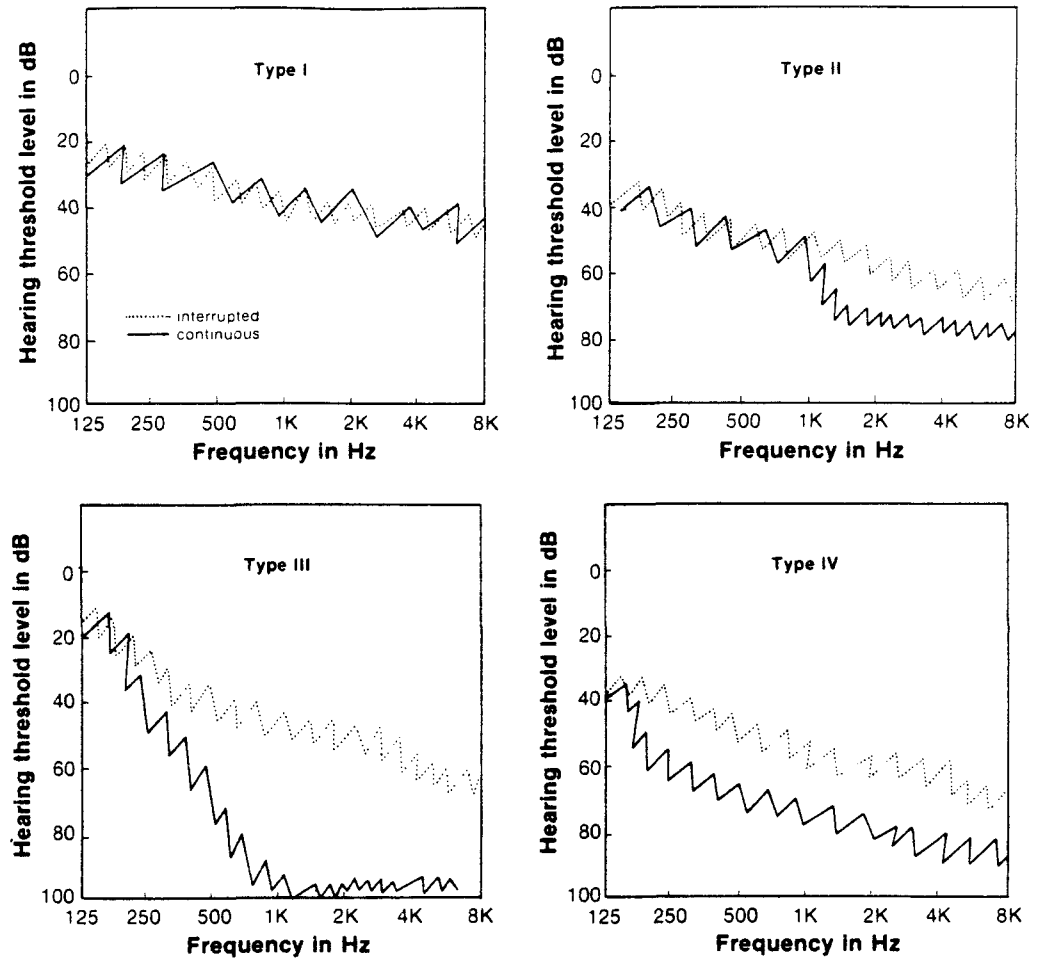


Figure 1. The four types of Békésy sweep frequency tracings as described by Jerger (1960).

In terms of site-of-lesion assessment, a Jerger Type I pattern indicates no adaptation and is associated with normal hearing and conductive losses. A Jerger Type II pattern suggests moderate adaptation and is often seen with cochlear losses. Types III and IV are considered to show abnormal adaptation and are associated with retrocochlear disorders. In Jerger's study, no known retrocochlear disorder ever gave a Type I or II tracing (Jerger, 1960).

There are several problems associated with conventional Bekesy audiometry. One of these is the difficulty in differentiating between the Jerger Type II and Type IV patterns (Hughes, Crabtree and Winegar, 1967). Another significant difficulty is that some patients with confirmed retrocochlear lesions do not demonstrate either a Type III or IV tracing. Johnson (1968) reported that 34% of 158 confirmed acoustic neuroma patients had a Jerger Type II pattern, which is generally associated with cochlear pathology.

Several modifications of the conventional procedure have been created to increase the sensitivity of Bekesy audiometry in the assessment of tone decay (Konkle and Orchik, 1979). One such modification is the use of fixed frequencies instead of the sweep frequencies. Any frequency can be tested, although 500,

1000 and 2000 Hz are most commonly used. The resulting tracings are classified into Jerger Types I through IV. This modification has been found to be slightly more sensitive to retrocochlear disorder, especially when compared to the sweep frequency tracings (Jerger, 1960).

The critical off time (COT) procedure involves systematically reducing the interstimulus interval (ISI) of the pulsed signal. While the duration of the pulse itself remains at 200 msec, the ISI is systematically varied between 20 and 500 msec. Patients with retrocochlear disorders often show a severe increase in threshold at a certain critical off time duration. This can vary from 40 to 200 msec, depending on the patient. As the COT is decreased past the critical point specific to each patient, threshold sensitivity drops accordingly and the Type III pattern emerges (Jerger, 1966).

A second modification of Bekesy audiometry is the forward-backward (FB) procedure. A high to low frequency continuous tracing is made after the low to high frequency continuous tracing and the two are subsequently compared. Jerger (1972) suggested that the magnitude of the discrepancy between the two tracings would be the critical factor when determining if a site-of-lesion was retrocochlear or cochlear in nature. He defined an abnormal FB difference as follows: a

separation of greater than 10 dB over at least two octaves, a separation of more than 30 dB over at least one octave, or a separation of more than 50 dB over at least 1/2 octave. While 99% of patients with cochlear hearing losses passed the criteria, only 20% of patients with retrocochlear hearing losses passed the same criteria. Jerger recommended that the continuous backward tracing become an integral part of Bekesy audiometry for the assessment of abnormal adaptation.

Finally, the Bekesy comfortable loudness procedure (BCL) described by Jerger (1974) is also considered to be more sensitive to retrocochlear disorders than conventional, COT, and FB Bekesy audiometry. Standard Bekesy tracings (pulsed and continuous) are obtained at the patient's comfortable loudness level. The tracings are then compared and assigned to one of six different types. There are three negative types and three positive types, labelled N1,2,3 and P1,2,3 respectively. The N1 pattern consists of interweaving interrupted and continuous tracings throughout the entire sweep frequency range. The N2 pattern is characterized by a continuous tracing that runs slightly above the pulsed tracing, and the N3 pattern has a continuous tracing that breaks away from the pulsed tracing at some point and then stabilizes below and parallel to the continuous

tracing. The P1 tracing is characterized by a sharp drop to the limits of the equipment of the continuous tracing. The P2 pattern is characterized by the continuous tracing falling substantially below the pulsed tracing in only the low frequencies. The P3 tracing is obtained using the FB procedure, and has an interweaving pattern in the forward mode, however there is a significant forward-backward discrepancy (Jerger and Jerger, 1974).

MANUAL PURE TONE MEASURES

In addition to automatic audiometry, there are many manual pure tone methods for the assessment of auditory adaptation, both threshold and suprathreshold. The Carhart (1957) procedure is considered to be the basic model for manual pure tone techniques: a tone is presented below threshold, and the intensity is then raised until the patient responds. Testing is recommended for octave intervals between 500 and 4000 Hz. Once the patient responds, the duration of the tone is held for one minute, and if the patient can respond for the full minute the test is terminated. If not, the intensity is raised in 5 dB steps without terminating the signal so one can measure the continuous adaptation of the system. A tone is presented at each level until the patient is able to respond for one minute at a given level. If the patient is unable to perceive the tone for one minute at any level, or tone decay persists over a range of 30 dB from threshold (Yantis, 1959), the patient is said to have abnormal tone decay, suggesting a retrocochlear lesion. Several investigators (Yantis, 1959, Morales-Garcia and Hood, 1972) modified the Carhart procedure and recommended having the test begin at 5 dB SL instead of threshold to provide an easier

listening task for the patient.

Sorensen's (1961) procedure is similar to Carhart's except that it is restricted to 2000 Hz and requires perception of the tone by the patient for 90 seconds. Based on previous auditory research by de Mare's and Rossler (1950), Sorensen determined that tone decay was most pronounced at frequencies above 1000 Hz, and that by choosing only one test frequency, efficiency could be increased. The 90 second duration time was to insure that the sustained response, not the "on-effect" of the auditory system was stimulated. Abnormal adaptation was defined as a continuous increase in threshold over the test period.

Rosenburg (1958) recommended that the tone decay testing be terminated at the end of one minute whether or not the tone was heard for the full 60 seconds. This was advised even if the tone had to be raised one or more levels during the presentation time. This modification was designed to elicit a renewed response to the tone each time it was presented. Rosenburg had four categories of scores based on the dB of tone decay over the 60 second test period. Normal: 0 to 5 dB; mild: 10 to 15 dB; moderate: 20 to 25 dB; and marked: 30 or more dB of decay.

Hood (1955) recommended yet another variation:

beginning the test at 5 dB SL and recording the length of time the tone is heard at that level up to a full one minute presentation. When the listener no longer hears the tone, it is turned off for one minute to allow complete recovery from adaptation. The presentation level is then raised 5 dB and the signal is presented again. The degree of tone decay is expressed as the difference between the point where the patient could hear the tone for the full minute and their threshold. Owens (1964b) modified Hood's procedure, by recommending that the tone be terminated for only 20 seconds rather than a full minute between presentations to reduce testing time and patient fatigue. Owen's procedure and classification system is described under the heading "Temporal Features" earlier in this paper.

Olsen and Noffsinger's (1974) modification is based on the theory that by beginning at 20 dB SL, persons with a cochlear disorder who would possibly show abnormal tone decay at threshold but not at higher sensation levels would be screened out, and therefore the test would have a higher specificity for those patients with retrocochlear disorders without sacrificing sensitivity (Jerger, 1974, 1975 and Olsen and Noffsinger, 1974) The Olsen-Noffsinger modification is quite similar to the Carhart protocol, however the

initial presentation level of the test signal begins at 20 dB SL. This modification was felt to provide an easier task for the patient and save valuable clinical time. Patients with cochlear disorders are also screened out. This procedure has been demonstrated to be more specific to retrocochlear disorders than earlier manual pure-tone techniques, as well as being more efficient clinically (Olsen and Noffsinger, 1974).

For the above manual pure tone testing procedures, the amount of threshold tone decay is reported as the difference between threshold and the sensation level at which the test was terminated. If a patient has 30 dB or more of decay, the test is considered indicative of retrocochlear lesion, regardless of its rapidity (Yantis, 1959; Olsen and Noffsinger, 1974).

Supra-threshold tone decay testing procedures are considered by many investigators to be as sensitive to retrocochlear disorders as are the threshold tone decay procedures (Jerger, 1974; Olsen and Noffsinger, 1974; Jerger and Jerger, 1975). If tone decay is present, it seems to occur first at higher intensities and as the disease progresses, it is seen closer to threshold. So testing at higher intensities would allow the diagnosis of retrocochlear disorder cases at an earlier date (Jerger, 1975; Turner, 1984). Finally, beginning the

test well above threshold provides an easier listening task for the patient.

Jerger and Jerger (1975) described the supra-threshold adaptation test (STAT). During this protocol, the test signal is presented for a one minute duration at only one level, 110 dB SPL at the test frequencies: 500, 1000, and 2000 Hz. The patient responds for as long as they can hear the tone. If the patient demonstrates a continued response for a full 60 seconds, the test is considered negative for abnormal adaptation while any shorter response is considered positive. This test is based on the hypothesis that symptoms of abnormal auditory adaptation appear first at only the highest intensity levels. While a patient with a larger lesion might show adaptation at lower intensity levels, it is in the early stages of retrocochlear disorder that the presence of any cochlear symptoms may mask the retrocochlear involvement at low sensation levels. Therefore testing at the high intensities will be sensitive to early retrocochlear signs. The authors described three advantages of the STAT over conventional tone decay procedures:

- 1) It takes very little time.
- 2) There is a lower false positive rate.
- 3) Abnormal adaptation is sought where it is most

likely to be found.

ADAPTATION AND CHANGE IN TIMBRE

The previous discussion described the various Bekesy and manual pure-tone techniques for the assessment of auditory adaptation at threshold and supra-threshold levels. However, Green (1963) recommended yet another modification designed to increase the sensitivity of these procedures. He suggested instructing the patient to indicate any change in the perceived tonality of the signal as well as any decrease in its audibility. That is, the patient is to respond if the tone became a buzz or had changed pitch during its presentation. Green used the Rosenberg procedure, but instructed the patient to respond to the stimulus only as long as it was tonal. This is termed the Modified Tone Decay Test (MTDT). Green theorized that a perceived change in tonality could provide stronger evidence for a retrocochlear disorder. He reported that larger amounts of tone decay are shown when the subject is instructed to respond to tonal stimuli only, as opposed to responding to any perceived stimuli.

There are some problems with this theory. Green's

modification is based on case studies, not experimental data. He also did not obtain any normative data, nor did he account for giving the subjects a preset expectation. These difficulties raise several questions as to the effectiveness and accuracy of the modification.

Canavet, Scharf, and Botte (1985) reported that they have informally observed that perception of tone quality decreases in tonality or increases in "fuzziness" over time, whether or not true adaptation of the tone occurs over time. However, they also did not have experimental data to validate this phenomenon.

The first systematic measure of tone quality change was performed by Barratt and Hood (1984). Listeners were asked to rate the "fuzziness" of a tone under two conditions:

- 1) When accompanied by a comparison tone
- 2) Without a comparison tone.

They determined that, for normal listeners, the "fuzziness" of a tone increased as the length of the presentation time increased. More "fuzziness" was noted as the presentation time exceeded one minute, as well as in the comparison tone conditions, since using a comparison tone made the detection of change easier for the subject. Barratt and Hood concluded that the time

course of the decrease in tonal quality parallels the time course of loudness adaptation, since the underlying neurological processes could be one and the same. It is a general property of the nervous system to adapt over time to constant stimulation.

Two principles may have emerged from the Barratt and Hood study:

- 1) The auditory neurological system adapts over time to continuous stimulation in normal listeners, and
- 2) A change in the quality of pure tones presented to the ear can be detected by normal listeners both with and without a comparison tone.

Therefore, if adaptation is a normal function of the auditory system and changes in tone quality are perceived concurrently with adaptation, then stimulus quality change should be present in normally hearing subjects using a conventional tone decay test procedure.

However, the Barratt and Hood study had several flaws that may have reduced the applicability of their data to clinical tone decay tests.

- 1) The use of a comparison tone provided a reference for the subject that is not present in standard clinical testing.
- 2) They presented tones for five minutes instead of

the typical one minute presentation.

3) The scaling procedure they used does not account for differing perceptions of the subjects. At the start of the test the purity of the tone as the subject perceived it was assigned the value of 1, however one does not know if the subject perceived that tone as pure.

4) The set of instructions given to the subjects could influence their judgements. If a person is told to expect a change in tonality, they may think they perceive it even if it is not there.

The problems listed above make it difficult to apply Barratt and Hood's data to clinical tone decay tests. The present study investigated whether normal listeners do indeed perceive a change of tonality during routine clinical tone decay testing. It is hypothesized that perceived changes in tone quality do not occur in normal listeners at low sensation levels unless instructed to perceive such a change.

CHAPTER 2

METHODS

Subjects

Forty subjects, ages 18-29 years, participated in the present study. All subjects were required to have no significant history of otological pathology as determined by a case history questionnaire (see appendix A). The subjects were also required to pass an audiological screening battery: Pure-tone air conduction thresholds at 10 dB HL or better for octave intervals between 250 and 8000 Hz in both ears, normal tympanograms consisting of pressure-compliance functions not exceeding ± 100 mm H₂O and within the range of .28 to 2.5 cc static compliance values and the presence of contralateral acoustic reflexes at 100 dB HL for 500, 1000, and 2000 Hz tonal stimuli presented to each ear. In addition, they were required to have no clinical or academic experience with tone decay testing as determined by a questionnaire.

Equipment

All pure tone testing was performed in an IAC sound-treated audiometric suite, model #1400 ACT, that meets ANSI 1977 standards, using a Grason-Stadler 10 audiometer and TDH-50 earphones with TDH 50P MX4/AR cushions. The system was calibrated quarterly and daily to ANSI 1969 and 1981 standards using a Bruel and Kjaer (B&K) sound level meter (2203), a B&K one inch condensor microphone (4121), and B&K Artificial Ear (4152). An Amplaid 702 impedance bridge with an earphone calibrated to the ANSI 1969 standard was used for acoustic immittance screening procedures.

Procedure

The test procedure was as follows: The subjects were divided into four groups by random assignment. The questionnaire was administered (see appendix A) and the subjects were screened at 10 dB for pure tone air-conduction thresholds at octave intervals between 250 and 8000 Hz in both ears. Tympanograms were performed, and contralateral acoustic reflexes were screened at 100 dB HL for 500, 1000, and 2000 Hz tonal stimuli presented to both ears.

All subjects received the Olsen-Noffsinger (1974) tone decay test procedure. A pure-tone was presented to the right ear of the subject for one minute at 2000 Hz at 20 dB SL. The subjects were instructed to indicate if the tone was perceived by raising their hand for as long as they could hear it. Subjects in Groups A and C were instructed before the tone decay test procedure to respond to any change in tone quality of the signal. Subjects in Groups B and D were asked at the end of the tone decay test if they had perceived any change in tone quality of the signal during its presentation. Subjects in Groups A and B listened to a continuous tone presentation while subjects in Groups C and D listened to a pulsed tone presentation with a pulse duration of 500 msec, and a 50% duty cycle.

The data were summarized into a 2X2 partition table describing the proportion of positive and negative responses to the change in the tonality of the signal under the four conditions: continuous vs pulsed tone and prior vs post instructional set. The subtables of observed and expected frequencies are presented in Figures 2 and 3. A chi square test for partitioned tables and the 2X2 contingency table was performed on the data and then tested for the existence of significant differences at $\alpha = 0.05$ (Fleiss, 1981).

CHAPTER III

RESULTS

The purpose of this research was to determine if normally hearing subjects perceived a change in tonality when presented with a standard test of tone decay. The subjects' perceptions of loudness and tonality change were investigated across two instruction sets. A change in tonality was defined as any increase or decrease in pitch and or change in timbre. A change in loudness was defined as an increase or decrease in the perceived loudness of the stimulus. The results are summarized in Figures 2, 3, 4 and 5. The subjects in all groups who described a change in loudness consistently reported a decrease in loudness except for three subjects in the pretest instruction, pulsed stimulus condition, who described the change in loudness as "fading in and out." The subjects in all groups consistently described the change in tonality as a decrease in pitch except for two subjects in the pretest instruction, pulsed stimulus condition. Subject #6 described the pitch as "warbling", and subject #38 described the change in tonality as "rising in pitch".

Figure 2 presents the observed occurrences in each response condition as a function of instructional set. When any perceived changes in loudness and tonality were examined together, with pretest instructions, there were no subjects in either the continuous or pulsed stimulus conditions who described a change in the stimulus. With posttest instructions, two of the ten subjects in the continuous and three of the ten subjects in the pulsed stimulus condition described a change in loudness and tonality.

When examining for only a perceived change in tonality, with pretest instructions, one of the ten subjects in the continuous stimulus group and one of the ten subjects in the pulsed stimulus group perceived a change in the tonality of the stimulus. With posttest instructions, one of the ten subjects in the continuous stimulus group perceived a change in the tonality of the stimulus and there were no subjects in the pulsed stimulus group who perceived any change in tonality.

When examining for only a perceived change in the loudness of the stimulus with pretest instructions, one of the ten subjects in the continuous stimulus condition described a change in loudness, and three of the ten subjects in the pulsed stimulus condition described a change in loudness. With posttest instructions, three

of the ten subjects in each of the continuous and pulsed stimulus conditions described a change in loudness.

Table 1 summarizes the results of X^2 computations of partitioned tables for perceived changes as a function of instructional set. The X^2 analysis indicated that the pre- and posttest instructions were not statistically significant in regards to the distribution of observations for a change in the loudness or tonality of the stimulus, i.e. instructional set did not appear to have a direct relation to the nature of the subject's responses. Even though the results were not significant, an evaluation of the size effects (0) suggested that the posttest instructions had a greater effect on the perception of a change in tonality while the pretest instructions had a greater effect on the perception of a change in loudness. For changes in loudness and tonality, the posttest instructional set had its greater effect on the perception of changes in loudness and tonality combined, but only by a very small amount.

Figure 3 presents the total observed occurrences in each response condition as a function of instructional set. When examining for any perceived changes in tonality with pretest instructions, one of the ten subjects in both the continuous and pulsed stimulus

conditions described a change in tonality. With posttest instructions, three of the ten subjects in both stimulus conditions described a change in tonality. When examining for any perceived changes in loudness, with pretest instructions, not one subject in the continuous condition described a change in the stimulus; however, three of the ten subjects in the pulsed stimulus condition described a change in loudness. With posttest instructions, five of the ten subjects in the continuous stimulus condition and six of the ten subjects in the pulsed stimulus condition described a change in loudness.

Figure 4 presents the observed occurrences in each response condition as a function of stimulus. When examining for any perceived changes in loudness and tonality taken together, one of the ten subjects in the pretest instruction group and two of the ten subjects in the posttest instruction group described a change in the perception of the stimulus in the continuous condition. In the pulsed stimulus condition, there were no subjects in the pretest instruction group and three of the ten subjects in the posttest instruction group who described a change in the perception of both tonality and loudness.

When examining for any perceived changes in

tonality alone, one of the ten subjects in each of the pretest and posttest instruction groups described a change in the tonality of the signal in the continuous stimulus condition. In the pulsed stimulus condition, only one of the ten subjects in the pretest group and no subjects in the posttest instruction group described a change in the tonality of the stimulus.

When examining for any perceived changes in loudness alone, one of the ten subjects in the pretest and no subjects in the posttest instruction group described a change in the loudness of the stimulus in the continuous condition. For the pulsed stimulus condition, three of the ten subjects in each of the pretest and posttest instruction groups described a change in the loudness of the stimulus.

Table 2 presents the results of the X^2 computations of partitioned tables for perceived changes as a function of stimulus. Again, the statistical analysis indicated that neither the continuous or pulsed stimulus condition was significant in regards to the distribution of observations for a change in the loudness or tonality of the stimulus, indicating that the nature of the stimulus was not directly related to the subject's responses. However, the results of an analysis of the size effects (0) suggested that the

pulsed stimulus condition had the most effect on the perception of a change in tonality. For the perception of a change in loudness, the continuous stimulus condition had the most effect. The pulsed condition had a slightly larger effect than the continuous stimulus condition for any change in the perception of loudness and tonality combined.

Figure 5 presents the total observed occurrences in each response condition as a function of stimulus. When examining for any perceived change in tonality, in both the continuous and pulsed stimulus conditions, one of the ten subjects in the pretest and three of the ten subjects in the posttest instruction group described a change in tonality. When examining for any perceived changes in loudness, in the continuous stimulus condition, none of the subjects in the pretest and 5 of the ten subjects in the posttest instruction group described a change in loudness.

Figure 2: Observed Occurrences in Each Response Condition as a Function of Instructional Set

Perceived Changes in Tonality Alone

		Δ	NO Δ				
Pretest	C	1	9	Posttest	C	1	9
	P	1	9		P	0	10

Perceived Changes in Loudness Alone

		Δ	No Δ			Δ	No Δ
Pretest	C	1	9	Posttest	C	3	7
	P	3	7		P	3	7

Perceived Changes in Loudness and Tonality

		Δ	NO Δ			Δ	NO Δ
Pretest	C	0	10	Posttest	C	2	8
	P	0	10		P	3	7

Key: C=continuous stimulus
 P=Pulsed stimulus
 Pretest=pre-instructional set
 Posttest=post-instructional set

Figure 3: Total Observed Occurrences in Each Response Condition as a Function of Instructional Set

Perceived Changes in Tonality

		Δ	No Δ
Pretest	C	1	9
	P	1	9
Posttest	C	3	7
	P	3	7

Perceived Changes in Loudness

		Δ	No Δ
Pretest	C	0	10
	P	3	7
Posttest	C	5	5
	P	6	4

Key: C=continuous stimulus
 P=pulsed stimulus
 Pretest=pre-instructional set
 Posttest=post-instructional set

Figure 4: Observed Occurrences in Each Response Condition as a Function of Stimulus

Perceived Changes in Tonality Alone

		Δ	No Δ			Δ	No Δ
cont	pre	1	9	pulsed	pre	1	9
	post	1	9		post	0	10

Perceived Changes in Loudness Alone

		Δ	No Δ			Δ	No Δ
cont	pre	1	9	pulsed	pre	3	7
	post	3	7		post	3	7

Perceived Changes in Loudness and Tonality

		Δ	No Δ			Δ	No Δ
cont.	pre	1	9	pulsed	pre	0	10
	post	2	8		post	3	7

Key: pre=pre-instructional set
 post=post-instructional set
 cont.=continuous stimulus
 pulsed=pulsed stimulus

Figure 5: Total Observed Occurrences in Each Response Condition as a Function of Stimulus

Perceived Changes in Tonality

		Δ	No Δ			Δ	No Δ
Cont.	pre	1	9	pulsed	pre	1	9
	post	3	7		post	3	7

Perceived Changes in Loudness

		Δ	No Δ			Δ	No Δ
Cont.	pre	0	10	pulsed	pre	1	9
	post	5	5		post	3	7

Key: pre=pre-instructional set
 post=post-instructional set
 cont.=continuous stimulus
 pulsed=pulsed stimulus

Table 1: Results of χ^2 Computations of Partitioned Tables for Perceived Changes as a Function of Instructional Set

CONDITION			
TONALITY			
Set	χ^2	p	ϕ
Pretest	0.00	0.5263	0.00
Posttest	1.14	0.5000	0.2387
Total	1.14	0.5000	0.2387
LOUDNESS			
Set	χ^2	p	ϕ
Pretest	1.25	0.2477	0.25
Posttest	0.00	0.3715	0.00
Total	1.25	0.2477	0.25
TONALITY AND LOUDNESS			
Set	χ^2	p	ϕ
Pretest	0.00	1.0	0.00
Posttest	0.19	0.34828	0.097467
Total	0.19	0.34828	0.097467

$\chi^2=3.84$ at $\alpha=0.05$
 p=probability
 ϕ =size effect

Table 2: Results of X^2 Computations of Partitioned
Tables for Perceived Changes as a Function
of Stimulus

CONDITION			
Stimulus	X^2	TONALITY	
		p	\emptyset
Continuous	0.00	0.5263	0.00
Pulsed	1.14	0.5000	0.2387
Total	1.14	0.5000	0.2387

Stimulus	X^2	LOUDNESS	
		p	\emptyset
Continuous	1.25	0.2477	0.25
Pulsed	0.00	0.3715	0.00
Total	1.25	0.2477	0.25

Stimulus	X^2	TONALITY AND LOUDNESS	
		p	\emptyset
Continuous	2.22	0.3947	0.333
Pulsed	2.99	0.1052	0.3866
Total	5.21	0.0286	0.5104

$X^2=3.84$ at $\alpha=0.05$
p=probability
 \emptyset =size effect

CHAPTER IV

DISCUSSION

The statistical analysis of the results indicated that neither the instructional set nor the type of stimulus had any significant effect upon the subject's responses in the perception of changes in loudness and tonality. Most subjects did not describe any changes in the tonality or in the loudness of the stimulus. Those subjects that did were most often in groups where loudness adaptation should not have occurred, i.e. the pulsed stimulus condition. This suggests that the instructional set may have some effect on the subject's perception of loudness and tonality.

The results of computations of partitioned tables indicated that while none of the results were statistically significant, the instructional set may have influenced the nature of the change in stimulus perception when a change was observed. The greatest effects (0) were seen for the posttest instructional set and pulsed stimulus condition when any change in tonality was examined. If a change in loudness was examined, the greatest effect was seen for the pretest instructional set and continuous stimulus condition.

The review of the literature suggested the

hypothesis that those subjects who received a continuous tone would be more likely to perceive a change in loudness and possibly tonality than those subjects who received a pulsed tone. The neurological system is believed to adapt to continuous stimuli, but not to pulsed stimuli, since the interruption of the stimulus allows for the recovery from adaptation (Aran, 1973). Since the presentation of pulsed stimuli would allow for the recovery from adaptation to occur, loudness adaptation should not have been perceived in the pulsed stimulus conditions. However, since some subjects reported a perception of loudness decrease in the pulsed condition, one can hypothesize that the instructional set may indeed have an effect upon the subject's perception of loudness adaptation. A review of literature on memory stores indicates that a subject's short-term memory can be affected by both the time interval between two stimuli and the type of stimuli (Cowan, 1984). Therefore, it appears that both the pre-instructional set and the post-instructional set can affect the memory trace of the signal. In the pre-instructional set condition, the subjects in this study were required to process and remember a set of directions pertaining to the stimulus. In contrast, the post-instructional set required the subjects in this

study to remember the perceived parameters of the stimulus. Thus the memory trace of the pre-instructional set is interrupted by the stimulus, while the memory trace of the stimulus is interrupted by the post-instructional set. Thus, the results of this study indicate that instructional set may have an effect on the results from tone decay testing.

Pirolli (1984) reported that memory can be altered by using leading questions that contain information inconsistent with the original information presented. This theory would support why the subjects in this study reported a loudness change in the pulsed stimulus condition even when no adaptation should have occurred. The presentation of the post-instructional set could have interfered with memory of the stimulus.

It is assumed that reported changes in tonality may be related to the same phenomenon leading to the reported changes in loudness. However, data are not available for the comparison on any perceived changes in tonality. A tonality change could be perceived if the subject also perceived a change in loudness. A variety of studies in psychoacoustics have demonstrated that a change in the frequency of a sound can cause the subject to perceive a change in both the pitch and loudness of the sound and a change in intensity of a sound can also

cause a perceived change in these same psychological constructs (Scharf, 1978). Therefore, it is possible that a perceived change in loudness (due to adaptation) may also result in a perceived change in pitch. This would account for those subjects receiving a continuous stimulus who reported a change in both the pitch and in the loudness of the stimulus.

To summarize, it appears that the instructional set may have an effect on the results of a tone decay test. If subjects report a perceived change in loudness to a pulsed stimulus, which should not change due to the nature of the stimulus and current adaptation models of the auditory system, then it can be supposed that the instructional set is having an effect. In addition, any reported changes in the perception of tonality may also be caused by the same phenomenon: the instructional set, and, therefore may not be diagnostically significant.

The results of this study differed from results of previous studies of perceived changes in tonality associated with auditory adaptation. Canavet, Scharf, and Botte (1985) informally observed that perception of tone quality decreases in tonality over time, whether or not adaptation occurs. In the present experimental study, the subjects described the perception of tone

quality changes as a pitch change, not a timbre or quality change. The differences between the results of this study and Canavet, Scharf and Botte's informal observations may be due to the use of experimental methodology rather than relying on simple informal observation. Barratt and Hood (1984) performed the first systematic measure of tone quality change. They used a comparison tone in the opposite ear and a five minute presentation time to evaluate tone quality change, in contrast with the present study which used a standard tone decay test protocol. They reported that as the length of presentation time increased, the "fuzziness" of the tone increased. However, they noted that the largest increase in "fuzziness" occurred as the presentation time exceeded one minute. The stimulus in the present study never exceeded a one minute presentation time, and no comparison tone was used. Therefore, the differences in the results of this study from those of Barratt and Hood's may be due to the differences in the protocols used for determination of tone quality change. Subjects in the present study were not specifically instructed to listen for "fuzziness" of the tone, but were asked to report and describe any change noted (see appendices B and C). The five minute presentation time and the use of the comparison tone in

the Barratt and Hood study may have also influenced the subject's perception of the stimulus tone. A one minute stimulus presentation time with no comparison tone was used in the present study, as is common to most standard tone decay test protocols. The additional time and the comparison tone may have provided more opportunity for the subject's perceptual experience to change.

The hypothesis for this research was that normally hearing subjects would not perceive a change in tone quality unless instructed to do so. The results were inconclusive in that there were no statistically significant trends either in favor of or opposed to this hypothesis. However, the results do suggest that factors such as instructional set may influence the subject's perception of tonality and loudness. Clearly, more research is needed to determine how instructional set affects diagnostic test protocols such as tone decay testing, especially when using a modification (perception of tonality) as examined in the present study. This would permit a stronger diagnostic test in the evaluation of retrocochlear disorders.

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APPENDIX A

QUESTIONNAIRE

1) Have you had any ear infections or ear surgery as an adult or as a child? If so, please describe when and how it was treated.

2) Has there been any health problem with your ears that has been treated medically? If so, please describe.

3) Have you had any clinical or academic experience with tone decay testing?

4) Do you have any reason to think that your hearing might not be normal?

APPENDIX B

PRETEST INSTRUCTIONS

Pre-test: All Groups

"You will hear a tone in your right ear. Please raise your right hand when you hear the tone, and keep it up for as long as you hear it. When you no longer hear the tone, lower your hand. Do you understand?"

Pre-test for groups A and C:

"If you notice any change in the pitch, timbre, or quality of the tone during the presentation, please indicate by raising your other hand."

(If they raise hand, ask at the end of the test to "describe the change they perceived").

APPENDIX C

POSTTEST INSTRUCTIONS

Post-test for groups B and D:

"Did you notice any change in the tone?"

If response is "no", discontinue testing.

If response is "yes":

Ask them to "Please describe the change."

If they can't describe it:

"Did the pitch change?"

"Did the quality change?"

"Did the timbre change?"

"Did the loudness change?"